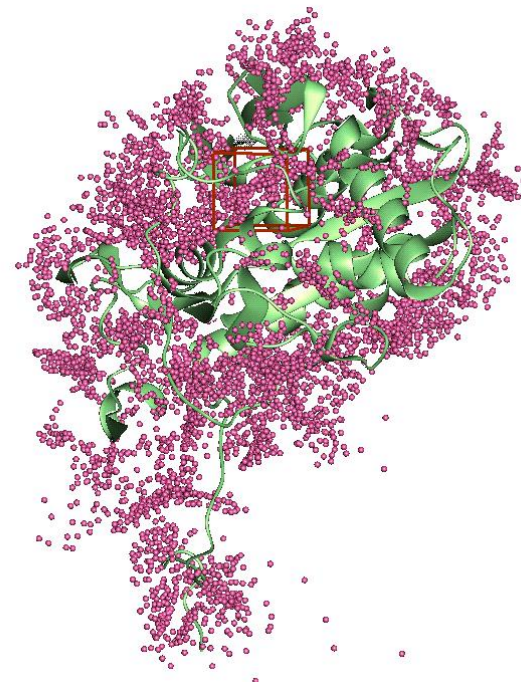
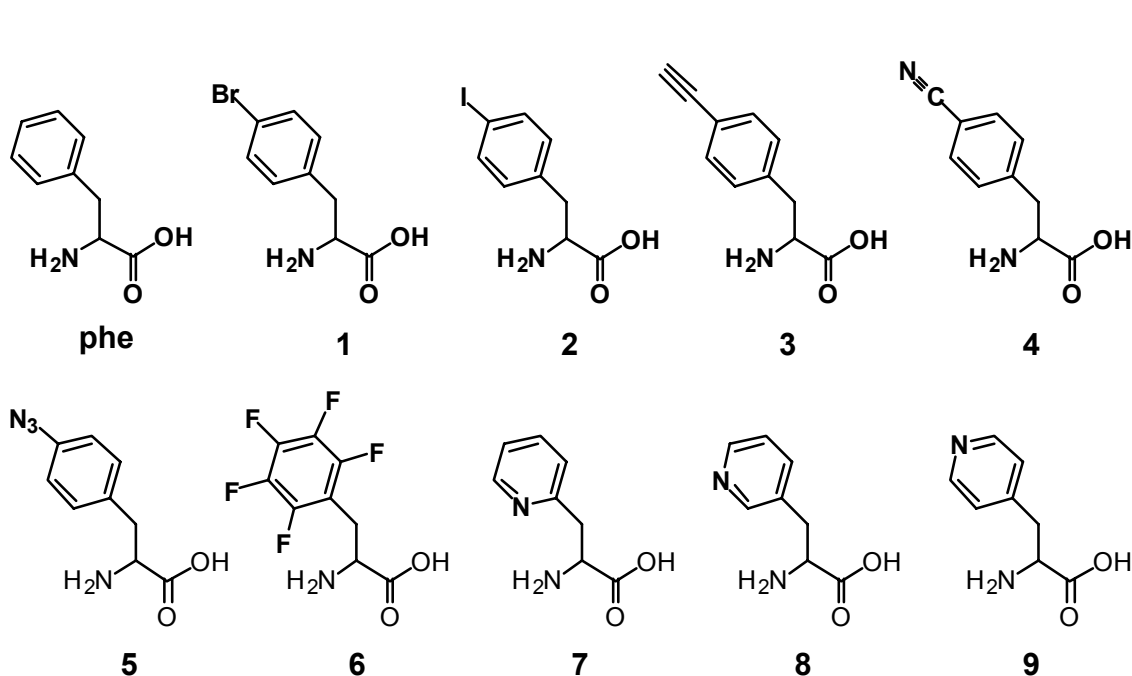


# Adding Letters to Life's Alphabet

## CalTech MRSEC "Center for the Science and Engineering of Materials"



Kirshenbaum, Carrico and Tirrell, *ChemBioChem* (2002)

Wang, Nagarajan, Tirrell and Goddard, submitted (2002)

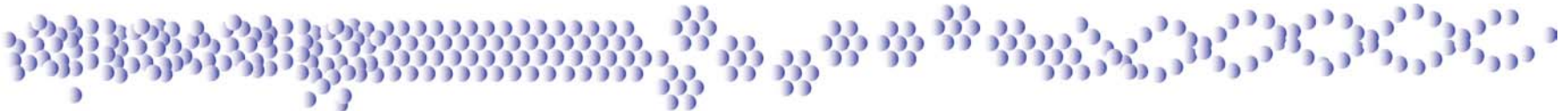


# Explanation

In a story on the front page of the Science Times section of the New York Times (July 24, 2001), Andrew Pollack featured the work of Caltech MRSEC researchers (and others) who are pursuing the creation of novel protein-like macromolecules. To quote Pollack, "The research goes well beyond current genetic engineering, which involves reshuffling the ordinary components of DNA or proteins into new combinations or moving DNA from one organism to another. Adding completely new elements to DNA and proteins is essentially rewriting the genetic code, the fundamental language of life." At Caltech, this effort has focused on creating the machinery necessary to build artificial proteins with useful material properties, including materials to be used in surgical reconstruction, in medical diagnosis, or in detection and elimination of undesirable chemical and biological species. This research is necessarily highly collaborative, involving biologists, chemists, physicists, engineers and physicians, and can thrive only in the rich multi-investigator environment fostered by the Materials Research Science and Engineering Centers.

The slide shows eight new derivatives of the natural amino acid phenylalanine (phe), seven of which have been used to modify natural proteins and to build novel macromolecular materials by expression of artificial genes in bacterial cells. One of the amino acids (6) has not yet been shown to work as a phenylalanine surrogate.

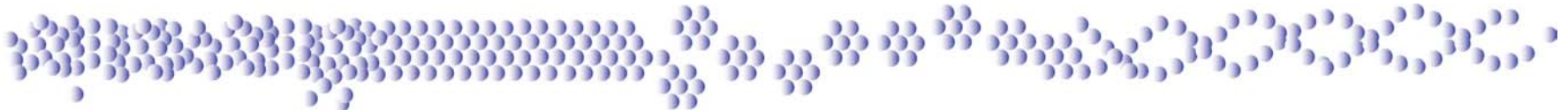
The key to expanding the set of building blocks for proteins lies in understanding the aminoacyl-tRNA synthetases, the enzymes that activate amino acids so that they can be incorporated into proteins. The structure on the right shows the synthetase that activates phenylalanine (the structure shown is the result of a computational prediction of the site where phenylalanine binds to the enzyme). Caltech researchers have modified this enzyme to allow it to activate the other analogs, and to outfit proteins with new chemical functions not found in nature. The new amino acids are being explored as tools for structure determination, as reagents for photocuring of protein films, and as handles for convenient labeling of proteins for functional studies.



## **Broader Impacts**

---

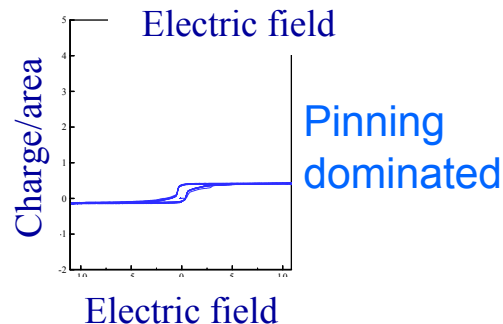
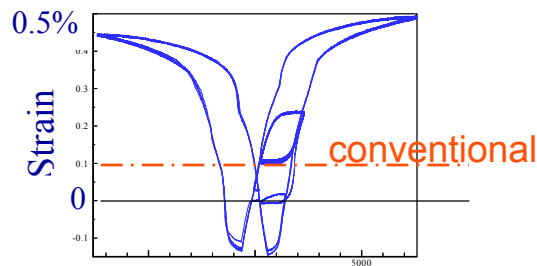
- The synthetase design project of the Caltech Center for the Science and Engineering of Materials is intended to effect fundamental changes in the field of macromolecular chemistry. The project bridges the gap that has traditionally separated biological and technological macromolecules, and draws on disciplines ranging from molecular biology to computational materials science.
- Students work jointly with Bill Goddard in computational molecular design and with David Tirrell in protein and polymer synthesis, and move easily from the wet laboratory to the materials simulation center.
- The project provides an effective vehicle for the Materials Partnership that links Caltech and the California State University at Los Angeles. Kevin Nielson, a Minority Undergraduate Research Fellow from CSULA, is currently working full-time at Caltech on new materials applications of novel amino acids.



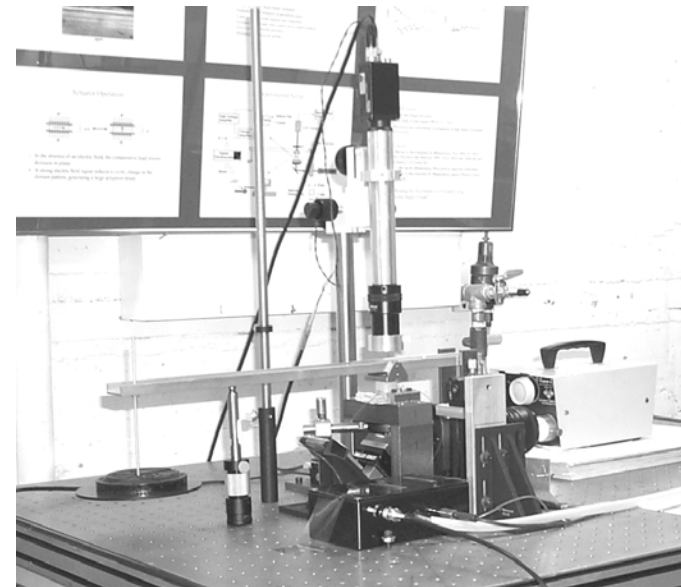
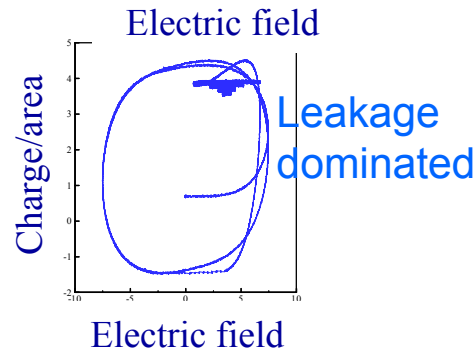
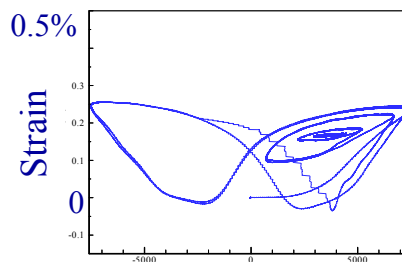
# Pushing the Boundaries: Large Electrostriction in Ferroelectrics

- Designing materials to allow domain boundaries to migrate with only mild fatigue provide large enhancements in the strain that can be induced in ferroelectrics.

**Before fatigue**

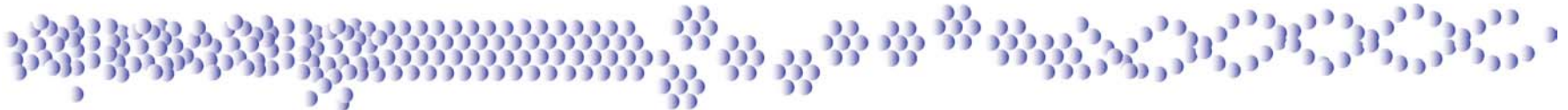


**After fatigue**



Unique instrument to observe domain boundaries during switching.

**Ravichandran and Bhattacharya**

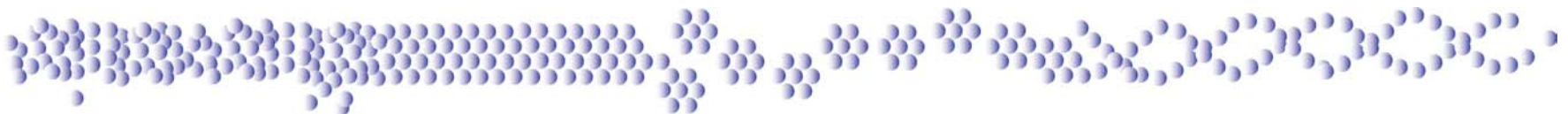


# EXPLANATION

---

Certain crystalline solids have a substantial polarization along one crystal axis; this provides a basis for changing the shape of the material by applying an electric field or for transducing a change in shape by the change in voltage across the material. The conventional wisdom regarding electrostriction in these materials is to avoid motion of domain walls for fear that it leads to fatigue. The Caltech team has tested this view using a combination of exceptionally well-defined materials and a novel instrument they developed to simultaneously observe the motion of domain boundaries while recording the electro-mechanical response of the material. Their findings show that by creating materials in which the crystal orientation is compatible with migration of domain walls greatly enhancements in accessible strain are possible (graph in the upper left shows strain up to 5x larger than conventional ferroelectrics); movies of domain boundaries show they translate smoothly in the linear regime, then “stick” (pinning) and at high enough field move again, providing a microscopic view of the basis of the inflection in the strain vs. applied field curve. After over a thousand cycles, the magnitude of the strain response is still 3x greater than for conventional materials. Based on the observed leakage current (lower graphs), most of the reduction in performance is due to the creation of charged defect sites in the crystal during repeated cycles of applied high voltage. Thus, the moof domain boundaries per se appears not to be the primary cause of fatigue; rather, the reduction in mobility of domain boundaries due to the injection of charged defects appears to be the culprit in fatigue.

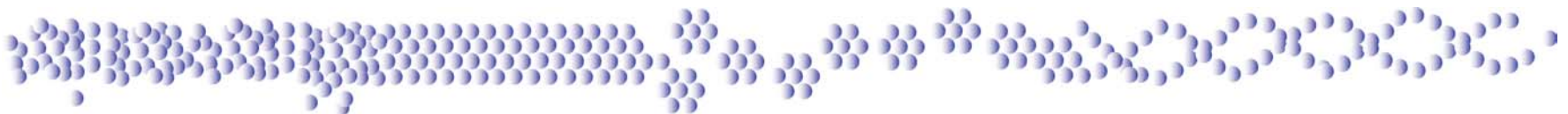
Thus, the discoveries arising from the Seed project in Ferroelectrics open a new way of approaching the design of ferroelectric materials to achieve large amplitude response for actuators and sensors. Go ahead and push the boundaries!



# Broader Impacts

---

- **Demonstration of 500% improvement in the strain that can be achieved using ferroelectric materials expands the scope of microelectromechanical systems (MEMS) that can be developed, with potential applications in micro-robotics and autonomous systems.**
- **This Seed project of the MRSEC led to establishment of the ARO MURI “Engineering Microstructural Complexity in Ferroelectric Devices” involving 9 PIs at Caltech, plus collaborators at ARL and LLNL.**



# EXPLANATION

---

Integrated mechanical, electronic and optical systems are revolutionizing diverse technologies from biomedicine to automotive technology. Microscopic actuators require materials that undergo relatively large shape changes under the influence of an applied electric field. A 5-fold increase in the magnitude of the shape change that can be induced in ferroelectric materials expands the range of devices that can be envisioned and actually built.

In addition to broad civilian applications, intense interest for defense applications has inspired the Army Research Office to fund a five year effort that builds on the Seed team (Bhattacharya, Ortiz, Ravichandran and Goddard) by expanding into growth of ferroelectric thin films (Haile, Atwater, Goodwin), detailed characterization of defect structures (Ustundag) and control strategies for taking advantage of the nonlinear response of these materials (Murray). Thus, the interdisciplinary effort initiated with Seed funds from the Caltech MRSEC has led to a substantial, long-term effort to pursue the new concepts that were proved using Seed funding.

For further information, please contact the leader of the Ferroelectrics Seed, Kaushik Bhattacharya at [bhatta@caltech.edu](mailto:bhatta@caltech.edu).

